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Silicon Solar Wafers: Quality Control and Improving the Mechanical Properties

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Abstract

Additionally to the electrical properties of silicon solar wafers and cells, the mechanical properties (especially strength) must also need to be scrutinized investigated. This paper describes several aspects regarding silicon wafer crystal structure, saw-damage removal and surface roughness parameters in relation to mechanical strength. The results may be used to increase production yields, which ultimately leads to reduced cell costs.

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Keywords: silicon solar wafers, fracture strength, additional control, quality.

1. Introduction

To determine the nature and source of defects and to provide information regarding the strength of cells, it is necessary to examine the mechanical properties of silicon solar wafers. The following factors are going to affect the fracture strength of a processed silicon wafer: surface roughness, crack defects at the edges, the amount of grain boundaries and the saw-damage layer thickness. In order to improve and ensure the overall quality of a certified crystalline module it is important to include the additional control [1-26].

2. The mechanical properties of silicon solar wafers

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2.1. Effect of saw-damage removal and silicon wafer surface roughness on mechanical strength

When Si ingots are cut into thin wafers, a multi-wire sawing process is used, which creates a highly stressed and damaged layer. Figure 1 shows an SEM micrograph of a typical surface of an as-sawn multicrystalline silicon wafer in order to check for phase transformations in the damaged layer. Hence, the Raman spectrum indicated the presence of a-Si beside polycrystalline Si on the as-sawn surface, because silicon shows a phase transformation when indented or scratched at low load. When the scratch is slow enough it creates a mixture phases (amorphous and metastable). In this study, amorphous silicon was found only in the smooth grooves (Fig. 1).

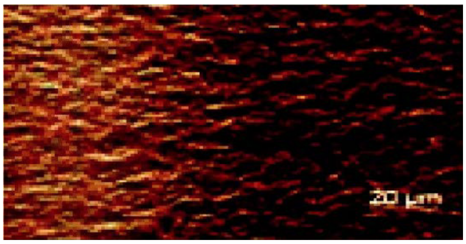

Fig.1. SEM micrograph of a typical surface of an as-sawn multicrystalline silicon wafer

As-cut specimens and specimens etched by an acidic solution (HF + HNO3 + CH 3COOH) for 30s were used to examine the impact of saw-damage etching on the strength of silicon wafers. Table 1 depicts the specimens with no additional etching have a lower Waybill characteristic strength, σo, which is due to presence of microcracks and a transformed amorphous silicon phase at the surface. Also, the depth of surface microcracks is reduced and some cracks disappear completely after the etching process. The layer of transformed a-Si is removed. All of these effects reduce the risk of microcrack formation, making the material less susceptible to failure. Tab. 1 [1]

Table 1. Effect of damage-layer removal on Waybill characteristic strength (σ_o) and modulus (m)

Etching conditions	σ_o (MPa)	m(-)
No etching	155	9.4
With etching	234	8.3

To analyze the effect of surface roughness, three types of specimens were prepared: the as-cut (with saw-damage layer), a textured surface (an in-line process, used to remove the damaged layer and to create a highly textured silicon surface for trapping the light) and a chemically polished surface (15µm removal from both wafer surfaces).

A significant increase in surface roughness - compared to the as-cut state - is shown by samples with a textured surface and despite this increase there is still an improvement in mechanical strength of textured samples, probably due to the removal of the damaged layer. As a result of the etching-texturing (damaged layer removal) process, there is an increase of strength of the mc-silicon wafer for about 50%. Hense, the density of micro-cracks in the damaged layer is a more important factor affecting mechanical strength of silicon wafers than surface roughness.

Without the demaged layer, the fracture strength is inversely proportional to the surface roughness, i.e. σo ~1/Ra, where σo is the fracture strength and Ra is the surface roughness, and soon as it's removed, the surface roughness profile is the second most detrimental factor affecting mechanical strength of silicon wafers.

2.2. Effect of multicrystalline (mc) silicon wafer crystallinity on mechanical strength

The effect of crystallinity features on the mechanical strength of the silicon wafer were examined by preparing 15 neighboring specimens (thus featuring the same crystallinity features)., The wafer specimens were divided by group into six crystallinity types: one big grain, a triple junction, many small grains, a twin boundary, several grains and a grain boundary perpendicular to the loading direction. Fig. 2 [1]

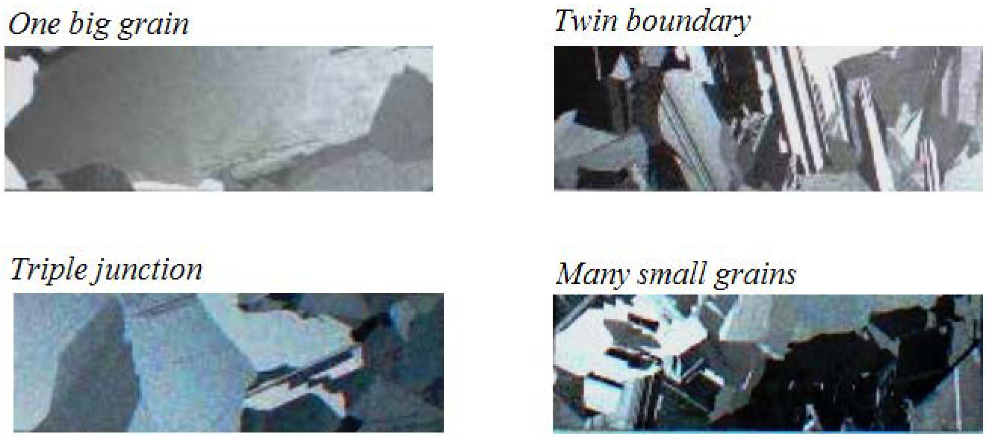

Fig.2 . Four of the groups of specimens showing different crystallinity features

To remove the damage induced by the sawing process, specimens were etched and polished. Equation 1 analyzes the four-point bending strength, and the strength results may define three main characteristic groups. Higher strength was found in specimens with one big grain in the middle than in those with many small grains in the middle. The four other crystallinity types - having several grains in the middle - maintain an intermediate strength. Tab. 2 [1]

Table 2 . Effect of crystallinity type of polished wafers on mechanical strength

Crystallinity type	σ_o (MPa)	*m*(-)
One big grain	293	8.5
Twin boundary	274	8.9
Triple junction	268	6.7
GB parallel to the loading direction	266	9.1
Several grains	260	7.4
Many grains	251	6.9

3. The additional control in oder to improve quality

Solar panels are expected to have a guaranteed service time of 20 to 30 years with typical degradation rates of 0.3-0.5% of STC power output for crystalline modules. However, recent failures in the open field have indicated that theoretical and actual service time can differ significantly. In this paper, the results of studies that focused on peel-off test, gel content and potential degradation are presented.

3.1. Eva gel content test

Lamination quality depends of the encapsulant material. The encapsulant material made of ethylene vinyl acetate (EVA) is used in PV module, produced as a film and delivered and stored in rolls protected against humidity and light. It is recommended storage at a temperature below 30°C and a relative humidity below 50% for a maximum period of 6 months after production. Initially, the polymer is a thermoplastic, but the manufacturer adds a curing agent, peroxide, which decomposes with decreases in temperature and starts a chemical reaction. When that is over , the original thermoplastic has become an elastomer, which can no longer be melted and material is the irreversibly cured. Fig. 3. [2]

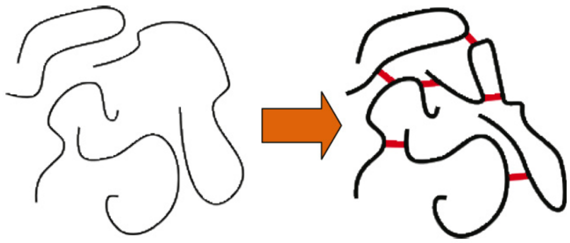

Fig.3. Schematic of the EVA curing process

Yet there are some problems involving EVA use. Due to incorrect storage or mistakes made on producer side, evaporation of the curing agent before curing may occur. The next problem is that too high or too low temperature for curing may have been chosen which can result in a partial curing and material may be irreversibly damaged. Also, because of ultra-fast, or similar curing sheets, in combination with the increase in module size, the curing process might not be completed across the whole module (the problem is the time difference between the curing temperature reaching the centre and the corner of a module). In addition, thermal stress may result in bending of the module, which lifts parts of the module away from the laminatory surface and reduces heat transfer and temperature development

3.2. The peel-off test

The peel-off test checks adhesion and consists of measuring the force required to separate the module layers. It is possible to test adhesion between encapsulant material and the back side of the solar cells; encapsulant material and the bus bars; encapsulant material and the front glass; layers between back-sheet material. The module is prepared by preliminary cuttings of 1cm-wide strips at the centre of the back sheet of the module. This test has to be initially manual in order to have 1cm long free strip, which can be clamped in the wedge grip. Then, an increasing force is applied to the wedge grip, and the specific force is recorded in N/cm at the point when the strips starts to separate from the module. There is no standard defined for this test yet. Fig. 4 [2]

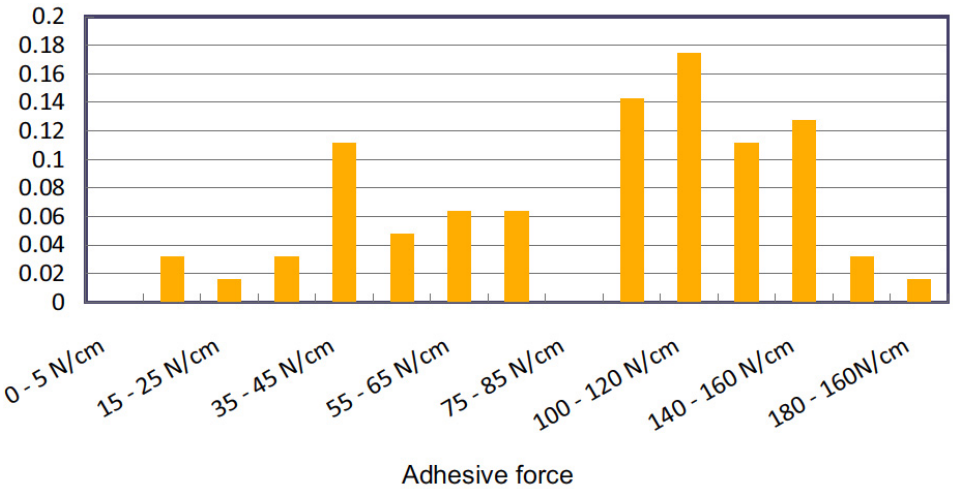

Fig.4. Frequency distribution of the measured adhesive force between EVA and glass

4. Potential induced degradation

Potential induced degradation (PID) is known as the effect when the STC power output of PV modules degrades due to electrical potential between the frame and the cells. The results of this process can be detected via an electroluminescence analysis. It can be detected by a reduced fill factor, but in advanced stages of the process the short circuit current decreases as well. The affected cells no longer contribute to power output and are recognized as ‘black cells’ in electroluminescence images. When modules are installed, PID first affects modules with the highest electrical potential and those located near to the ground, or frame parts with water inside. For the majority of c-Si modules, the PID effect is almost completely reversible. The sensitivity of cells to PID can be detected in accelerated damp heat climate chamber tests. The modules were treated for 48 hours in a dump heat chambers (85°C and relative humidity of 85%), with a potential of-1000V at the terminals. The results for a large number of tests range from a total power loss to no effect on STC power output. Fig. 5 [2]

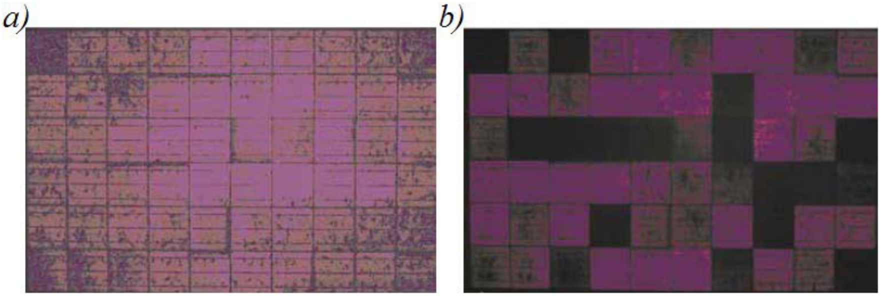

Fig.5. Result of an accelerated PID test in a climate chamber. Module initial state (a) and module after (b)

5. Conclusions

It is very important to study the mechanical properties of silicon solar wafers, in order to determine the nature and cause of the damage and to provide as much information concerning the firmness of cells. The strength of fractures of wafers mainly depend on the following factors: the thickness of the damaged layer by cutting, surface roughness, cracks at the edges and the number of boundaries between the grains. It is also important to include additional controls to ensure and improve the overall quality of certified crystalline modules.

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